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Posted Date: 9 January 2026

doi: 10.20944/preprints202601.0725.v1

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Effects of Straw Particle Size and Physical Forms of Corn in Starter Diets on Growth Performance and Rumen Parameters in Holstein Calves During the Pre-Weaning Period

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Simple Summary

This study evaluated the interactive effects of straw particle size (short or long) with two physical forms of corn (ground or whole) in the diets offered as total mixed rations on growth performance of calves during the preweaning period. In the diets including short chopped straw, weaning body weight, daily weight gain, starter intake and feed efficiency were similar for the calves fed ground or whole corn. In the diets including long chopped straw, inclusion of whole corn into the diet led to higher weaning body weight and daily weight gain and better feed efficiency compared with the diet including ground corn. The lowest weaning body weight and daily weight gain were observed in calves fed the total mixed ration with long chopped straw and pelleted concentrate including ground corn. Thus, this study indicated that long chopped straw and pelleted concentrate provision together might not be an appropriate combination to improve growth performance in pre-weaning calves.

Abstract

This study evaluated effects of straw particle size (short or long) and corn physical form (ground or whole) in diets on growth performance, rumen fermentation and fecal score in calves. Sixty female newborn calves were randomly assigned to one of the four treatments: 90% pelleted starter and 10% short straw (PSS); 70% pelleted starter, 20% whole corn and 10% short straw (PWCSS); 90% pelleted starter and 10% long straw (PLS); 70% pelleted starter, 20% whole corn and 10% long straw (PWCLS). In PSS and PLS treatments, all amount of corn was within pelleted starter. Calves were weaned at 68 days of age. Body weight (BW), wither height and heart girth were measured at 3 and 68 days of age. Feed intakes and fecal scores were measured daily. Rumen fluid and blood samples were collected for rumen pH, rumen volatile fatty acid (VFA) and blood β-hydroxy butyrate (BHB) measurements at 68 days of age. Weaning BW, average daily weight gain (ADG) and weaning wither height were significantly lower in PLS compared to other treatments. Weaning heart girth was significantly lower in PSS and PLS than PWCSS and PWCLS. Feed intake was significantly higher for PWCSS than PWCLS. PWCLS had a significantly lower feed efficiency (starter feed intake/ADG) than PLS. No significant differences were observed for ruminal pH, ruminal acetate and blood BHB among the treatments. In the diets including short straw, ruminal propionate, butyrate and total VFA concentrations were significantly higher for PWCSS than PSS. In the diets including long straw, ruminal propionate level was significantly greater for PLS than PWCLS and ruminal butyrate and total VFA concentrations were not different for PLS and PWCLS. This study indicated that the effect of corn physical form (ground or whole) on ruminal propionate, butyrate and total VFA concentrations could vary depending on straw particle size. Fecal score was significantly lower in PSS compared to other treatments. In conclusion, long straw combined with pelleted concentrate reduced growth performance in pre-weaning calves. Whole corn inclusion in the diets with long straw increased ADG and weaning BW and improved feed efficiency.

Keywords: straw particle size; corn processing method; growth performance; rumen fermentation; dairy calves

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1. Introduction

During the pre-weaning period, dairy calves face tremendous physiological and metabolic challenges owing to the transition from monogastric to functional ruminal digestion. The transition from milk-fed pre-ruminants to functional ruminants is fundamental for their growth and health performance and a successful calf rearing program aims to maximize the growth potential of dairy calves early in life. Appropriate nutrition management for calves is essential in successful rearing programs for dairy farmers [1,2]. During the pre-weaning period of dairy calves, the physical and metabolic development of the rumen and the subsequent transition from monogastric form to functional ruminal digestion are mainly influenced by the solid feed intake and solid feed composition. Solid feeds for pre-weaning ruminants include starter concentrate feeds in various contents and forms and/or different forage sources. Starter concentrate feeds, especially cereal grains as a starch source, stimulate the rumen microbial population and volatile fatty acids production, which initiates rumen development. Within the scope of rumen development, rumen papillae development is stimulated by the fermentation of starter concentrate producing volatile fatty acids [1,3]. On the other hand, inclusion of forage into starter feeds during the pre-weaning period triggers early rumination and muscular development of the rumen [3–5].

Supplying forage to dairy calves has been a common practice [6–8]. Provision of forage might be beneficial in terms of stimulating rumination [4,9], preventing decreases in ruminal pH [5,10], decreasing ruminal parakeratosis [3,5] and the subsequent enhancing growth performance [5,11,12] in young calves. The effects of forage addition to starter feeds on growth performance and health status in young calves have been variable across studies owing to the source of forage [11,13], the proportion of forage in solid feed [14–16], forage provision method (free-choice provision vs total mixed ration) and physical characteristics of the starter feed [16,17]. A limited amount of forage in starter rations of young calves has appeared to positively alter rumen environment resulting in increased intake and improved feed efficiency [8,18]. Particle size of forage fed to calves has been investigated. Despite many studies investigating the effects of different particle size of forage on rumen and growth performance parameters in young calves, the optimum particle size of forage offered as a free-choice provision or total mixed ration (TMR) has not been clearly determined [6,8,19].

Different types [13,20,21] and/or processing methods [22–24] of cereal grains used in starter concentrate feeds affect the physical and metabolic growth of the rumen, the palatability and intake of solid feed and growth performance in young calves. Corn has been extensively incorporated in different forms in calf starter rations; whole [22,25], ground [24,26] and steam-flaked [24,27]. There is a growing interest in using whole grains, especially corn, as a potential alternative strategy instead of forage feeding in calves. Whole grains can lead to increased particle size of calf starter diet and probably result in better rumen health and function by preventing decreased ruminal pH causing papillae keratinization [25,28]. Lesmeister and Heinrichs [22] observed that calves fed starter feed with whole corn had higher rumen pH than calves offered starter feeds with dry-rolled, roasted rolled or steam-flaked corn. Kamyab-Fard et al. [25] reported that ruminal pH was affected by different

 doi:10.20944/preprints202601.0725.v1

levels of whole corn in starter feed and increasing the amount of whole corn replaced with ground corn led to increased ruminal pH in young calves fed forage-free starter feeds. A previous study by Gholizadeh et al. [26] investigated the effects of combining corn grain forms (ground vs whole) with forage (0 vs 10%) in calf starters. They reported that ruminal pH, VFAs concentrations, ADG and feed efficiency were not affected by physical form of corn (ground vs whole) in the starter diets, regardless of forage provision, during the pre-weaning period. In that study [26], the combination of whole corn and forage led to a lower starter feed intake without influencing performance during the pre-weaning period. These results have suggested that dairy farmers can use whole corn grain in starter feeds without any negative growth or health effect, which is important since grinding corn is additional step and expenditure [26].

Maximizing starter feed intake and rumen growth have been positively correlated with weight gain in preweaned calves, which is partly related to a greater milk production during the first lactation [29,30]. Since a great variation has been found among the calf studies examining effects of different forms of starter feeds (ground, pelleted, textured) and/or different forage provision methods (forage-free starter, free-choice provision or TMR), there is insufficient evidence for a recommended starter diet for improving the growth rates of dairy calves [13]. Therefore, our study aimed to investigate the interactive effects of different straw particle sizes with two different physical forms of corn grain (whole or ground) in the starter diets on growth performance and rumen fermentation of Holstein calves during the preweaning period.

2. Materials and Methods

The study was carried out at a commercial dairy farm (Tarfaş Holstein Dairy Farm) in Bursa, Türkiye. This study was conducted under a protocol approved by the Animal Care and Use Committee of Bursa Uludag University (decision no. 2022-03/13).

2.1. Calves, Management and Experimental Diets

Sixty Holstein female dairy calves (36.5 ± 3.5 kg of body weight at 3 days of age) were randomly assigned to one of the four treatments (n = 15 calves per treatment) in a completely randomized design, with a 2 × 2 factorial arrangement of treatments including (1) starter diet containing 90% pelleted calf starter (P; 34.60% ground corn) and 10% straw with short particle size as fed basis (PSS); (2) starter diet containing 70% pelleted calf starter (15.18% ground corn) plus 20% whole corn (PWC) and 10% straw with short particle size as fed basis (PWCSS); (3) starter diet containing 90% pelleted calf starter (P; 34.60% ground corn) and 10% straw with long particle size as fed basis (PLS); (4) starter diet containing 70% pelleted calf starter (15.18% ground corn) plus 20% whole corn (PWC) and 10% straw with long particle size as fed basis (PWCLS). In PSS and PLS treatments, all amount of corn grain was within pelleted calf starter.

Immediately after birth, calves were separated from their dams and housed in individual pens (1.2 × 2.0 m) bedded with clean straw which was refreshed daily. The front of each pen had 2 openings for access to pails mounted on the outside. Water was provided ad libitum in one pail and solid feed was provided ad libitum in the second pail. The calves were fed 5 L of previously frozen or fresh colostrum (Brix > 22%) during the first 12 h of life (2.5 L by 1 h after birth and 2.5 L at 12 h after the first feeding). On day 2 of life, calves received transition milk (5 L/day) in three equal meals. According to the farm's protocol, all calves were fed in plastic feeding buckets 6 L/day pasteurized whole milk from 3 to 14 days of age three times daily; 7.5 L/day from 15 to 42 days of age three times daily; 6 L/day from 43 to 49 days of age three times daily; 5 L/day from 50 to 56 days of age twice daily; 4 L/day from 57 to 63 days of age twice daily; and 2 L/day from 64 to 68 (the end of the study) days of age once daily. Milk was sampled weekly and analyzed for fat, crude protein, lactose and total solids using an infrared analyzer (FOSS, MilkoScan™ FT3, Denmark). The average composition of offered milk was 3.65 ± 0.06% fat, 3.29 ± 0.07% crude protein, 4.60 ± 0.07% lactose and 12.51 ± 0.13% total solids. The calves used in our study were in good health condition prior to beginning the experiment (3 days of age). All calves were weaned at 68 days of age (the end of the study).

The calves had free access to starter diet and water throughout the study (from 3 to 68 days of age). The starter diets provided as TMR were offered once daily at 0800 h to result in at least 5% residual feed (orts) over a 24 h period. Before the experiment, wheat straw was chopped to obtain short or long particle size (short straw or long straw) using a TMR mixer (Ak Agricultural Machinery Industry Co., İzmir, Türkiye). The particle size distribution of wheat straw with short particle size (short straw) and long particle size (long straw) were presented in Table 1. Pelleted calf starters used in TMRs with or without whole corn were formulated to have the same ingredients. Two different pelleted starters were prepared in respect to formulation and chemical compositions so that experimental starter diets as a TMR had similar nutrient contents. Main ingredients (cereal grains, protein sources and by-products) in pelleted starters were ground to pass through a 2 mm mesh. The pelleted calf starters were 20 mm in length and 3 mm in diameter. Ingredient and nutrient compositions of the pelleted starters used in TMRs with or without whole corn were given in Table 2. Ingredient and chemical compositions of experimental starter diets (PSS, PLS, PWCSS, PWCLS) were presented in Table 3. The starter diets offered as a TMR were prepared daily in a big bucket by manual mixing of diet components. Experimental starter diets were prepared from the same batches of wheat straw and corn grain to prevent the effects of nutritional variation of straw and corn variety on results. The calves were individually monitored twice daily by a farm veterinarian. Sick calves were treated by a veterinarian according to regular farm protocols.

Table 1. Particle size (minimum, maximum and mean ± standard deviation) distribution of chopped wheat straw fed to calves according to The Penn State Particle Separator (PSPS).

Particle size distribution, %	**Short straw**	**Long straw**
>19.0 mm		
Minimum	16.50	51.00
Maximum	17.67	54.70
Mean ± standard deviation	17.16 ± 0.50	53.06 ± 1.58
8.0-19.0 mm		
Minimum	45.12	19.57
Maximum	47.90	24.60
Mean ± standard deviation	46.41 ± 1.24	22.54 ± 2.13
1.18-8.0 mm		
Minimum	24.30	16.00
Maximum	26.47	18.86
Mean ± standard deviation	25.20 ± 0.92	17.26 ± 1.19
<1.18 mm		
Minimum	10.43	6.10
Maximum	12.09	7.83
Mean ± standard deviation	11.23 ± 0.79	7.13 ± 0.74

Table 2. Ingredient and nutrient compositions of the pelleted starters used in TMRs with or without whole corn.

Ingredient, % of as-fed	**Pelleted starter in TMR without whole corn**	**Pelleted starter in TMR with whole corn**
Corn	34.60	15.18
Barley	5.00	6.91
Soybean meal	16.77	20.96
DDGS[1]	11.40	14.85
Sunflower meal	3.86	4.83
Corn gluten meal	1.93	2.50
Rapeseed meal	0.50	0.63
Fractionated vegetable oil[2]	0.92	1.15

Soybean hulls	9.80	12.25
Wheat middlings	7.50	10.66
Rice bran	1.60	2.54
Molasses, beet sugar	2.00	2.38
Pellet binder[3]	1.20	1.50
Lime stone	1.18	1.48
Premix-1[4]	0.94	1.18
Salt	0.45	0.56
Premix-2[5]	0.25	0.31
Live yeast[6]	0.10	0.13
Nutrient compositions, % of dry matter		
Dry matter (% of as-fed)	88.08	88.3
Crude protein	22.25	25.81
Ether extract	4.26	4.59
Crude ash	8.30	10.13
Neutral detergent fiber	21.34	24.44
Acid detergent fiber	11.80	13.66
Acid detergent lignin	2.13	2.43

[1]DDGS: Corn dry distiller grain with soluble. [2]The fractionated vegetable oil (Evyap Oleo 1685, Evyap Sabun Malaysia Sdn Bhd Co., Johor, Malaysia) contained: Minimum 85% of palmitic acid (C 16:0). [3]The pellet binder (Megabind 100, Tempe Chemical Feed Additives Co., İstanbul, Türkiye) contained (per kg): 999.40 mg of Bentonite, 200 mg of Guar gum, 200 mg of Xantham gum, 200 mg of Gum Arabic. [4]The premix (Premix Balance BSMX GRAN, Cargill Agriculture and Food Industry Co., Sakarya, Türkiye) contained (per kg): 430 g of Calcium carbonate, 250 g of Magnesium oxide, 200 g of Sodium carbonate, 120 g of Sea algae. [5]The premix (Kavimix VM, Kartal Chemical Co., Kocaeli, Türkiye) contained (per kg): 6,500,000 IU of vitamin A, 1,500,000 IU of vitamin D, 50,000 mg of vitamin E, 250,000 mg of choline, 9,500 mg of niacin, 5,000 mg of pantothenic acid, 3,750 mg of riboflavin, 3,750 mg of thiamin, 2,500 mg of pyridoxine, 150 mg of folic acid, 50 mg of biotin, 40 mg of cyanocobalamin, 20,000 mg of Fe, 15,000 mg of Zn, 6,000 mg of Mn, 2,000 mg of Cu, 180 mg of I, 140 mg of Se, 8 mg of Co. [6]The live yeast (Yea-Sacc Ts, Alltech Biotechnology Co., Dunboyne, Ireland) contained (per kg): $1x10^{12}$ cfu of Saccharomyces cerevisiae (CBS 493.94). .

Table 3. Ingredient and chemical compositions of experimental starter diets.

Ingredient, % of as-fed	**PSS[1]**	**PLS[2]**	**PWCSS[3]**	**PWCLS[4]**
Wheat straw	10	10	10	10
Pelleted starter	90	90	70	70
Whole corn	-	-	20	20
Chemical composition, % of dry matter				
Dry matter (% of as-fed)	88.41	88.41	88.39	88.39
Crude protein	20.33	20.33	20.42	20.42
Ether extract	4.01	4.01	4.19	4.19
Crude ash	8.31	8.31	8.43	8.43
Starch	32.38	32.38	31.01	31.01
Neutral detergent fiber	27.10	27.10	27.37	27.37
Acid detergent fiber	16.04	16.04	15.92	15.92
Acid detergent lignin	3.01	3.01	3.05	3.05
Non-fiber carbohydrate[5]	40.36	40.36	40.61	40.61

[1]PSS: Total mixed ration contained 90% pelleted concentrate and 10% straw (short particle size). [2]PLS: Total mixed ration contained 90% pelleted concentrate and 10% straw (long particle size). [3]PWCSS: Total mixed ration contained 70% pelleted concentrate, 20% whole corn and 10% straw (short particle size). [4]PWCLS: Total mixed ration contained 70% pelleted concentrate, 20% whole corn and 10% straw (long particle size). [5]Non-fiber-carbohydrate was calculated as [100 - (Neutral detergent fiber + Crude protein + ether extract + Crude ash)] [51].

 doi:10.20944/preprints202601.0725.v1

2.2. Measurements, Sample Collection and Analyses

Particle size distribution of chopped wheat straw used in 4 experimental diets was determined using a Penn State particle separator (PSPS, Nasco, Fort Atkinson, WI, USA) equipped with 3 sieves (19, 8, and 1.18 mm) and a bottom pan. Chopped wheat straw samples (200 g) were collected 4 times throughout the study from each particle size group (short and long) for particle size distribution analysis. The pelleted starters used in TMRs with or without whole corn and experimental starter diets (PSS, PLS, PWCSS, PWCLS) were ground using a laboratory mill through a 1 mm screen for chemical analyses and then dried in an oven at 105 °C overnight. Nutrient analyses (crude protein, ether extract, starch and crude ash) of the pelleted starter and experimental starter diet samples were performed according to AOAC [31] and neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) analyses of the pelleted starters and experimental TMRs were performed as described by Van Soest et al. [32] in Department of Animal Nutrition and Nutritional Diseases, Bursa Uludag University Veterinary Faculty, Bursa, Türkiye.

Body weight (BW) and structural growth measurements (wither height; distance from the base of the front feet to withers and heart girth; circumference of the chest) were measured at 3 days of age (the beginning of the study) and 68 days of age (the end of the study) prior to the morning feeding. Average daily weight gain (ADG) was calculated as the difference between two BW measurements divided by days. Starter feed (TMR) intake was measured daily on an individual basis throughout the study, by subtracting refusals from the amounts offered. Feed efficiency (FE) was calculated by dividing average daily starter intake (kg) by ADG (kg).

Rumen fluid samples from each calf were obtained using a stomach tube fitted to a vacuum pump at 68 days of age (4 h after feeding). The first 15 mL of rumen fluid was discarded to eliminate the potential saliva contamination and then the rest of rumen fluid was collected. Thereafter, the samples were squeezed through 4 layers of cheesecloth, and then rumen fluid pH was immediately measured using a portable pH meter (Inolab pH, serial no: 00200018, pH Electrode SenTix 41, D-82362, Weilheim, Germany). For the analysis of volatile fatty acids (VFA), 4 mL of rumen fluid samples were acidified with 1 mL of 25% meta-phosphoric acid in plastic tubes. After the samples were centrifuged at 5000 rpm for 10 min, the supernatants were stored at -20 °C until the analysis. Ruminal VFA concentrations were determined using gas chromatography (Hewlett Packard Agilent Technologies 6890N Network GC System, Serial CN10447002, Beijing, China). A column (6 × 2 mm ID glass) was packed with 10% SP-1200/1% H_3PO_4 80/100 Chromosorb WAW (Supelco, Bellefonte, PA, USA). Carrier gas (N_2) flow was 30 mL/min, inlet temperature was 175 °C, detector temperature was 170 °C, and column temperature was 110 °C. Detection was carried out by flame ionization.

Blood samples were taken from the jugular vein of all calves into 10 ml evacuated tubes 3 h after morning feeding at 68 days of age. The concentrations of blood β-hydroxy butyrate (BHB) were immediately measured using blood ketone test strips (Abbott Diabetes Care Ltd., Range Road Witney, Oxfordshire, UK) with Abbott Precision Xtra™ meter (Abbott Diabetes Care Ltd., Range Road Witney, Oxfordshire, UK).

Before morning feeding, fecal samples were collected daily from each calf by retrieval from the rectum. Fecal samples were scored regarding consistency by the same researcher according to the following system: 1 = normal, 2 = soft to loose, 3 = loose to watery, 4 = watery, mucous, slightly bloody, and 5 = watery, mucous and bloody as described by Heinrichs et al. [33].

2.3. Statistical Analysis

Data of body weight, ADG and average daily starter feed intake (from 3 to 68 days of age), feed efficiency, structural growth measurements (wither height, hearth girth and the changes of wither height and hearth girth), ruminal pH, ruminal VFA concentrations (acetate, propionate, butyrate and total), blood β-hydroxy butyrate concentration and average daily fecal score (from 3 to 68 days of age) were analyzed by General Linear Models, where the groups were included in the models as fixed factors. Full factorial model was used as model for interaction effects between straw particle size and physical forms of corn. The threshold of significance was set at $p \leq 0.05$. Trends were declared when $0.05 < p \le 0.10$. All statistical analyses were conducted by using SPSS 29.0 software (IBM, Chicago, IL, USA).

3. Results

All calves used in our study consumed all the milk offered daily during the suckling period. Excluding diarrhea, no health problems such as respiratory diseases were observed and no mortality occurred during the study. The number of calves treated for diarrhea was one for PSS, PWCSS and PLS treatments and two for PWCLS treatment.

The results on body weight (BW), average daily weight gain (ADG), starter feed (TMR) intake and feed efficiency were presented in Table 4. BW at 3 days of age (the beginning of the study) was similar for all treatments ($p > 0.05$). BW at 68 days of age (weaning time) and ADG were lower for the calves fed PLS treatment than those fed other treatments ($p < 0.05$). Weaning BW and ADG were affected by particle size of straw, physical form of corn (ground vs whole) and their interaction ($p < 0.01$). A significant difference for starter feed intake was detected between PWCSS and PWCLS treatments. Starter feed intake was higher for PWCSS treatment than PWCLS treatment ($p < 0.05$). Starter feed intake was affected by particle size of straw in the diets offered as a TMR ($p < 0.01$). Physical form of corn did not affect starter feed intake ($p = 0.61$). The interaction between straw particle size and corn physical form was significant ($p = 0.05$) for starter feed intake. There was a difference in feed efficiency (kg of mean starter feed intake / kg of mean ADG) between PLS and PWCLS treatments. PWCLS feeding resulted in lower feed efficiency than PLS feeding ($p < 0.05$). The particle size of straw in starter diets did not affect feed efficiency ($p = 0.50$). Feed efficiency was influenced by physical form of corn in starter diets ($p < 0.01$). An interaction was observed between straw particle size and corn physical form in starter diets for feed efficiency ($p = 0.01$).

Table 4. Effects of straw particle size (short or long) and physical forms of corn in starter diets on body weight, average daily weight gain, starter diet intake and feed efficiency of dairy calves (n = 15 calves per treatment).

	Treatments[1]				SEM	*p*-Value[2]		
	Straw with short particle (SS)		Straw with long particle (LS)					
Item	P	PWC	P	PWC		SPS	C	SPS × C
BW3[3], kg	36.53	36.73	36.00	36.73	0.83	0.65	0.66	1.00
BW68[4], kg	86.53[a]	90.39[a]	79.07[b]	86.28[a]	2.02	<0.01	<0.01	<0.01
ADG[5], kg/d	0.76[a]	0.81[a]	0.65[b]	0.75[a]	0.30	<0.01	<0.01	<0.01
FI[6], kg/d	0.49[ab]	0.52[a]	0.46[ab]	0.45[b]	0.02	<0.01	0.61	0.05
FE[7]	0.65[ab]	0.64[ab]	0.71[a]	0.61[b]	0.03	0.50	<0.01	0.01

[1]Starter diet containing 90% pelleted calf starter (P) and 10% straw with short particle size as fed basis (PSS); Starter diet containing 70% pelleted calf starter plus %20 whole corn (PWC) and 10% straw with short particle size as fed basis (PWCSS); Starter diet containing 90% pelleted calf starter (P) and 10% straw with long particle size as fed basis (PLS); Starter diet containing 70% pelleted calf starter plus %20 whole corn (PWC) and 10% straw with long particle size as fed basis (PWCLS). [2]Statistical comparisons: SPS = straw particle size; C = physical form of corn in starter diets; SPS × C = interaction of straw particle size and physical form of corn in starter diets. [3]Body weight at 3 days of age. [4]Body weight at 68 days of age. [5]Average daily weight gain from 3 days to 68 days of age. [6]Mean starter feed (TMR) intake from 3 days to 68 days of age. [7]Feed efficiency = kg of mean starter feed (TMR) intake / kg of mean average daily weight gain. [a,b]Means within a row with different superscript letters are different ($p < 0.05$).

Structural growth measurements (wither height and heart girth) data were shown in Table 5. Wither height and heart girth measurements at 3 days of age were similar for all treatments ($p > 0.05$). Wither height at 68 days of age and the change of wither height were lower ($p < 0.05$) for PLS treatment than the other treatments (PSS, PWCSS and PWCLS). Wither height (68 days of age) and the change of wither height were affected by straw particle size ($p = 0.02$), physical form of corn ($p < 0.01$) and their interaction ($p < 0.01$). Heart girth (68 days of age) and the change of heart girth were lower for PSS and PLS treatments than PWCSS and PWCLS treatments ($p < 0.05$). There was a tendency for effect of straw particle size on heart girth at 68 days of age ($p = 0.08$) and heart girth change ($p = 0.07$) in favor of the calves fed the diets with short straw. Heart girth (68 days of age) and the change of heart girth were influenced by physical form of corn in the starter diets ($p < 0.01$) in favor of the calves fed the diets containing whole corn. The interaction between straw particle size and physical form of corn in starter diets was significant ($p < 0.01$) for heart girth (68 days of age) and the change of heart girth.

Table 5. Effects of straw particle size (short or long) and physical forms of corn in starter diets on structural growth measurements (wither height and heart girth) of dairy calves (n = 15 calves per treatment).

	Treatments[1]							
	Straw with short particle (SS)		Straw with long particle (LS)			*p*-Value[2]		
Item	P	PWC	P	PWC	SEM	SPS	C	SPS × C
WH[3], cm								
d 3	78.33	78.13	78.27	78.20	0.53	1.00	0.92	1.00
d 68	93.13[a]	94.33[a]	89.20[b]	94.60[a]	1.04	0.02	<0.01	<0.01
Change	14.80[a]	16.20[a]	10.93[b]	16.40[a]	1.02	0.02	<0.01	<0.01
HG[4], cm								
d 3	79.27	78.80	79.20	79.00	0.32	0.77	0.29	0.92
d 68	102.73[a]	107.53[b]	102.07[a]	105.27[b]	1.14	0.08	<0.01	<0.01
Change	23.47[a]	28.73[b]	22.87[a]	26.27[b]	1.15	0.07	<0.01	<0.01

[1]Starter diet containing 90% pelleted calf starter (P) and 10% straw with short particle size as fed basis (PSS); Starter diet containing 70% pelleted calf starter plus % 20 whole corn (PWC) and 10% straw with short particle size as fed basis (PWCSS); Starter diet containing 90% pelleted calf starter (P) and 10% straw with long particle size as fed basis (PLS); Starter diet containing 70% pelleted calf starter plus % 20 whole corn (PWC) and 10% straw with long particle size as fed basis (PWCLS). [2]Statistical comparisons: SPS = straw particle size; C = physical form of corn in starter diets; SPS × C = interaction of straw particle size and physical form of corn in starter diets. [3]Wither heights at 3 days of age and 68 days of age. [4]Heart girths at 3 days of age and 68 days of age. [a,b,c]Means within a row with different superscript letters are different ($p < 0.05$).

Ruminal pH and ruminal volatile fatty acid (VFA) concentrations at 68 days of age were presented in Table 6. Ruminal pH values did not differ among the treatments ($p > 0.05$). There was no difference in ruminal acetate concentration among the treatments ($p > 0.05$). In the diets including short straw, ruminal propionate, butyrate and total VFA concentrations were higher for PWCSS treatment than PSS treatment ($p < 0.05$). In the diets including long straw, ruminal propionate level was higher for PLS treatment than PWCLS treatment ($p < 0.05$) while ruminal butyrate and total VFA concentrations were similar for PLS and PWCLS treatments ($p > 0.05$). Ruminal propionate concentration was affected by straw particle size ($p = 0.02$), physical form of corn ($p < 0.01$) and their interaction ($p < 0.01$). Ruminal butyrate concentration was greater ($p < 0.05$) for PWCSS treatment than other treatments (PSS, PLS and PWCLS). There was a tendency for effect of straw particle size on ruminal butyrate ($p = 0.06$) and total VFA ($p = 0.09$) concentrations. Physical form of corn (ground vs whole) in starter diets affected mean ruminal butyrate and total VFA concentrations at 68 days of age ($p < 0.01$). The interaction between straw particle size and physical form of corn in starter diets was significant ($p < 0.01$) for ruminal butyrate and total VFA concentrations.

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Table 6. Effects of straw particle size (short or long) and physical forms of corn in starter diets on ruminal pH and volatile fatty acid (VFA) concentrations of dairy calves (n = 15 calves per treatment).

	Treatments[1]							
	Straw with short particle (SS)		Straw with long particle (LS)			*p*-Value[2]		
Item	P	PWC	P	PWC	SEM	SPS	C	SPS × C
pH[3]	6.06	5.80	5.76	5.81	0.13	0.12	0.13	0.15
A[4], mmol/L	33.16	36.72	35.91	33.23	2.12	0.80	0.12	0.58
P[5], mmol/L	23.94[ac]	29.41[b]	26.12[ab]	21.01[c]	1.81	0.02	<0.01	<0.01
B[6], mmol/L	8.84[a]	12.12[b]	9.64[a]	9.53[a]	0.65	0.06	<0.01	<0.01
T[7], mmol/L	65.94[a]	78.25[b]	71.67[ab]	63.77[a]	3.61	0.09	<0.01	<0.01

[1]Starter diet containing 90% pelleted calf starter (P) and 10% straw with short particle size as fed basis (PSS); Starter diet containing 70% pelleted calf starter plus % 20 whole corn (PWC) and 10% straw with short particle size as fed basis (PWCSS); Starter diet containing 90% pelleted calf starter (P) and 10% straw with long particle size as fed basis (PLS); Starter diet containing 70% pelleted calf starter plus % 20 whole corn (PWC) and 10% straw with long particle size as fed basis (PWCLS). [2]Statistical comparisons: SPS = straw particle size; C = physical form of corn in starter diets; SPS × C = interaction of straw particle size and physical form of corn in starter diets. [3]pH values at 68 days of age. [4]Ruminal acetate concentrations at 68 days of age. [5]Ruminal propionate concentrations at 68 days of age. [6]Ruminal butyrate concentrations at 68 days of age. [7]Total VFA (acetate + propionate + butyrate) concentrations at 68 days of age. [a,b,c]Means within a row with different superscript letters are different ($p < 0.05$).

Blood β-hydroxy butyrate (BHB) concentration at 68 days of age and fecal score results were shown in Table 7. Blood BHB concentration did not differ among the treatments ($p > 0.05$). Blood BHB concentration was not influenced by straw particle size ($p = 0.66$), corn processing method ($p = 0.18$) and their interaction ($p = 0.41$). In the diets including short straw, fecal score was higher for PWCSS treatment than PSS treatment ($p < 0.05$). In the diets including long straw, fecal score was higher for PWCLS treatment than PLS treatment ($p < 0.05$). Mean fecal score from 3 to 68 days of age was affected by straw particle size ($p < 0.01$) and physical forms of corn ($p < 0.01$) in the starter diets. An interaction was observed between straw particle size and physical forms of corn in starter diets for mean fecal score ($p < 0.01$).

Table 7. Effects of straw particle size (short or long) and physical forms of corn in starter diets on blood β-hydroxy butyrate (BHB) concentration and fecal score of dairy calves (n = 15 calves per treatment).

	Treatments[1]							
	Straw with short particle (SS)		Straw with long particle (LS)			*p*-Value[2]		
Item	P	PWC	P	PWC	SEM	SPS	C	SPS × C
BHB[3], mmol/L	0.16	0.16	0.17	0.13	0.02	0.66	0.18	0.41
Fecal score[4]	1.41[a]	1.82[bc]	1.69[b]	2.07[c]	0.10	<0.01	<0.01	<0.01

[1]Starter diet containing 90% pelleted calf starter (P) and 10% straw with short particle size as fed basis (PSS); Starter diet containing 70% pelleted calf starter plus % 20 whole corn (PWC) and 10% straw with short particle size as fed basis (PWCSS); Starter diet containing 90% pelleted calf starter (P) and 10% straw with long particle size as fed basis (PLS); Starter diet containing 70% pelleted calf starter plus % 20 whole corn (PWC) and 10% straw with long particle size as fed basis (PWCLS). [2]Statistical comparisons: SPS = straw particle size; C = physical form of corn in starter diets; SPS × C = interaction of straw particle size and physical form of corn in starter diets. [3]The concentrations of blood β-hydroxy butyrate at 68 days of age. [4]Fecal samples were scored daily with regard to consistency according to the following system: 1 = normal, 2 = soft to loose, 3 = loose to watery, 4 = watery, mucous, slightly bloody, and 5 = watery, mucous and bloody [33]. [a,b,c]Means within a row with different superscript letters are different ($p < 0.05$).

 doi:10.20944/preprints202601.0725.v1

4. Discussion

4.1. Growth Performance

Growth performance and feed intake of young calves could be affected by forage level (forage-free or different levels) in starter diet and forage provision method (free-choice provision or TMR) [16,34]. In the dairy calf feeding, supplementation of forage to the starter feed has been a common practice. However, data are limited about how different particle sizes of forage affect calf performance in free-choice provision or TMR feeding regimen [8,35]. In the current study, weaning BW, ADG and starter feed intake were affected by particle size of straw and were greater in the calves fed straw with short particle size than in those fed straw with long particle size. Omidi-Mirzaei et al. [6] investigated the interactive effects of forage source and forage particle size as a free-choice provision on growth performance of calves fed texturized starters. In contrast to our results, Omidi-Mirzaei et al. [6] reported that the particle size of forage did not affect weaning BW, ADG and total feed intake (forage intake and starter intake) during the pre-weaning period, which could be due to the differences in forage provision method and particle sizes of utilized forage between ours and that study [6]. Also, Bagheri et al. [8] observed that weaning BW, ADG, starter intake and forage intake were not influenced by straw particle size as a free-choice provision to calves during the pre-weaning period. An increase in starter feed intake has been correlated with greater ADG in pre-weaning calves [6,22,26]. In our study, feeding the diets containing short straw led to both higher feed intake and higher ADG compared with feeding the diets including long straw, regardless of physical forms of corn in starter diets. Similar to previous studies mentioned above [6,8], feed efficiency was not affected by straw particle size in our study. Montoro et al. [36] investigated effects of 10% coarsely chopped grass hay or 10% finely ground grass hay in TMR containing 90% crumb starter concentrate on performance and apparent digestibility of young calves from 2 to 56 days of age. In that study [36], there was a tendency for improved feed efficiency in the calves fed chopped hay compared with those fed ground hay. Montoro et al. [36] reported that total tract apparent digestibility of dry matter, crude protein, NDF and ADF during the week after weaning were greater in calves offered the diet including chopped hay than in those fed the diet with ground hay. This result could explain the tendency for an improved feed efficiency in calves fed TMR with chopped hay. According to Montoro et al. [36], it seemed that particle size of forage might play an important role in nutrient digestibility. Our result regarding feed efficiency were contrary to that of Montoro et al. [36] when we evaluated the effects of particle size of straw in the starter diets. These conflicting results were probably due to the differences in the type and particle sizes of utilized forages and forms (crumb starter vs pelleted or textured starter) of utilized starter concentrates between ours and that study [36].

It has been demonstrated that the physical form of the starter feeds as pelleted, texturized or ground [5,13,37] and processing methods of cereal grains used in starter diets [13,22,24] can affect starter intake and/or growth performance in young calves. However, the reported effects of physical form of starter diets on calf performance are complicated [13,23]. In our study, weaning BW and ADG were affected by physical form of corn despite no effect of ground versus whole corn on starter feed intake, regardless of forage particle size in TMR. The calves fed the diets containing whole corn had higher weaning BW and ADG than those fed the diets without whole corn. This result indicated that whole corn inclusion improved feed efficiency. Gholizadeh et al. [26] investigated the interactive effects of forage provision (0 or 10% of chopped straw) and physical form of corn (ground or whole) in the starter diets (mashed starter compared to a texturized starter containing whole grain) on growth performance of young calves. Contrary to our study, Gholizadeh et al. [26] reported that weaning BW, ADG and feed efficiency during the pre-weaning period were not influenced by physical form of corn in the starter diets, regardless of forage provision. In addition, Gholizadeh et al. [26] found that starter feed intake was higher for the calves offered the diet with ground corn than those offered the diet with whole corn during the pre-weaning period when the calves were fed TMR containing 10% of chopped wheat straw. These conflicting results between ours and that study [26] were probably due to the differences in particle sizes of straw used in starter diets since different

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particle sizes of forage could affect growth performance and/or starter feed intake of young calves [13,18,19]. The particle sizes of forage in our TMRs with both short and long particle size of straw were longer than those in the study conducted by Gholizadeh et al. [26]. In contrast to our results, Kamyab-Fard et al. [25] indicated that ADG and feed efficiency were similar for the calves fed the diets with or without whole corn when comparing forage-free starter diets containing 60% ground corn versus 40.2% ground corn and 19.8% whole corn. This discrepancy between ours and that study [25] was probably due to the differences in forage provision and/or form and composition of starter diets such as amount of corn and particle size distribution.

In our study, weaning wither height and the change of wither height were lower for the calves fed PLS than those fed PSS, PWCSS or PWCLS and were similar for PSS, PWCSS and PWCLS. Our results related to wither height were congruent with the findings of ADG and weaning BW. Rincker et al. [38] found that wither height at weaning was positively correlated with weaning BW and ADG during the pre-weaning period in Holstein female calves. In the diets including short straw, weaning heart girth and heart girth change were greater for PWCSS treatment (with whole corn) than PSS treatment. Similarly, in the diets including long straw, weaning heart girth and heart girth change were higher in PWCLS treatment (with whole corn) than PLS treatment. Similar results were observed for weaning BW. Silva et al. [39] indicated that body weight could be reliably estimated using heart girth measurements in preweaned Holstein–Friesian calves aged 1 to 90 days, which showed the relationship between body weight and heart girth.

4.2. Ruminal pH and Volatile Fatty Acids

In the current study, mean ruminal pH at 68 days of age ranged from 5.76 to 6.06 in neonatal calves and did not differ among the treatments. Supplementation of forage to the starter feeds prevents decreases in ruminal pH and ruminal acidosis in young calves [5,8,10,16]. Similar to studies in mature ruminants, changes in particle size of forage have been mainly investigated as one of the most known physical characteristics of forage to affect ruminal pH of young calves. Nemati et al. [14] observed that ruminal pH were affected by particle size of alfalfa hay mixed with finely ground concentrates, regardless of the level of forage (12.5 or 25%) in TMR and ruminal pH was higher for the calves offered medium particle size of forage than those offered fine particle size of forage. In contrast with the results of Nemati et al. [14], in our study, ruminal pH were not influenced by particle size of straw, which was probably due to the differences in the level of utilized forages and the form of starter concentrates between ours and that study [14]. Similar to the result of our study, Omidi-Mirzaei et al. [6] reported that the particle size of forage as a free-choice provision did not affect ruminal pH values in dairy calves. In addition, Bagheri et al. [8] also found that ruminal pH at weaning was not influenced by different particle sizes of wheat straw provided as a free-choice provision to dairy calves. Under the conditions of our experimental design, differences in particle size distribution of wheat straw between treatments had no effects on ruminal pH at weaning, which might be related to greater chewing activity in calves compared to cows and consequently a decrease in particle size of forage entering the rumen. Also, the calves fed the starter diets including different particle sizes of straw might have sorted for similar particle size of straw thereby showing similar ruminal pH [8].

Whole corn grain can lead to increased particle size of starter diet and probably result in better rumen health by preventing decreases in ruminal pH of young calves. Therefore, whole corn grain inclusion in calf starter diets can be considered as a potential alternative of forage feeding to modulate ruminal pH and improve rumen health [25,28]. Kamyab-Fard et al. [25] observed that ruminal pH was influenced by different levels of whole corn in starter feed and increasing the amount of whole corn replaced with ground corn led to increased ruminal pH in young calves fed forage-free starter feeds. In our study, the presence of a forage source in experimental starter diets may have caused the lack of effect of whole corn on ruminal pH. Similar to the result of our study, Gholizadeh et al. [26] reported that ruminal pH values were not affected by different physical form of corn (ground or whole) in the starter diets mixed with 10% chopped wheat straw in Holstein calves. The high level of

 doi:10.20944/preprints202601.0725.v1

milk feeding could lead to lower mean solid feed intake during the pre-weaning period [26,40], which may have caused in the lack of possible effect of straw particle size and physical form of corn in starter diets on ruminal pH in our study where calves fed 7.5 L/day milk from 15 to 42 days of age. For instance, the particle size of forage did not influence ruminal pH in the calves fed 6 L/day milk from 3 to 44 days of age [6]. In addition, Gholizadeh et al. [26] found that ruminal pH was not affected by wheat straw inclusion or corn grain physical form in the calves fed 8 L/day milk from 11 to 45 days of age and 6 L/day milk from 46 to 55 days of age.

In the present study, ruminal acetate concentrations were not affected by particle size of straw in starter diets. Molaei et al. [41] also reported that ruminal acetate concentrations were not affected by physical form (10% medium chopped vs 10% pelleted) of alfalfa hay mixed with starter concentrate in Holstein calves. In addition, Omidi-Mirzaei et al. [6] observed that the particle size of forage did not affect ruminal acetate concentrations in dairy calves. In our study, physical form of corn (ground or whole) in starter diets did not affect ruminal acetate levels. Similarly, Gholizadeh et al. [26] reported that ruminal acetate concentrations of dairy calves were not influenced by different physical form of corn (ground or whole) in the starter diets containing 10% chopped wheat straw. Additionally, Gholizadeh et al. [26] found that ruminal acetate concentrations were higher for calves fed diets with straw than those fed the diets without straw when considering forage inclusion (0 or 10% of chopped straw) into starter concentrate. Forage provision during the pre-weaning period can promote cellulolytic microbial growth and results in increased acetate production in the rumen of calves [42,43]. In our study, similar ruminal acetate concentrations for all treatments could be explained by same level of wheat straw used in experimental diets. In the present study, ruminal propionate concentration at weaning was affected by particle size of straw in starter diets and there was a tendency for effect of straw particle size on ruminal butyrate and total VFA concentrations at weaning. Similarly, Omidi-Mirzaei et al. [6] found that particle size of forage as a free-choice provision affected ruminal propionate, butyrate and total VFA concentrations in young calves, regardless of forage source. In our study, physical form of corn in starter diets significantly affected ruminal propionate, butyrate and total VFA levels at weaning. In the diets including short straw, ruminal propionate, butyrate and total VFA concentrations were higher for the treatment with whole corn (PWCSS) than the treatment without whole corn (PSS). On the other hand, in the diets including long straw, ruminal propionate level was greater in the calves fed the diet without whole corn (PLS) compared to the calves fed the diet with whole corn (PWCLS) and ruminal butyrate and total VFA concentrations were similar for PLS and PWCLS treatments. These results suggested that the effect of physical form of corn (ground or whole) on ruminal propionate, butyrate and total VFA concentrations could vary depending on particle size of straw in starter diets. This could be due to the differences in particle size distribution of starter diets resulting in feed sorting. In contrast to the results of our study, Gholizadeh et al. [26] reported that ruminal propionate, butyrate and total VFA concentrations of Holstein calves were not influenced by different physical forms of corn (ground or whole) in the starter diets containing 10% chopped straw with same particle size. These conflicting results between ours and that study [26] were probably due to the effect of forage particle size as mentioned above. In the study by Kamyab-Fard et al. [25], when comparing forage-free starter diets containing 60% ground corn versus 40.2% ground corn and 19.8% whole corn, ruminal butyrate and total VFA concentrations were similar for the calves fed the diets with or without whole corn while there was a tendency for lower ruminal propionate level in the calves offered the diet including whole corn than those fed the diet without whole corn. The results of ruminal propionate, butyrate and total VFA concentrations in that study [25] were similar to our results for the diets including long straw. However, in the diets including short straw, our results for ruminal propionate, butyrate and total VFA levels were different from the finding of the study by Kamyab-Fard et al. [25] and the reasons for different results could not be explained. Different results of whole corn inclusion in calf starter diets on ruminal VFA concentrations might be related to forage provision (forage-free or offering forage) and/or the absorption rate of VFAs produced in the rumen of young calves since the absorption of VFA can be a factor affecting its concentration in the rumen fluid [25,44]. In fact, numerically lower ruminal pH (5.80) for PWCSS treatment may have negatively influenced VFA absorption compared with PSS treatment (6.06) and thus higher ruminal propionate, butyrate and total VFA concentrations may have been found in PWCSS treatment than PSS treatment in spot sampling of rumen fluid 4 h after feeding, which was probably due to their slow absorption by the rumen wall [25,45]. Similarly, Kamyab-Fard et al. [25] indicated that the concentrations of ruminal total VFA were increased when ruminal pH values decreased in Holstein calves. In addition, Kitkas et al. [46] reported that ruminal propionate concentration elevated when ruminal pH values decreased in dairy cows.

4.3. Blood BHB and Fecal Score

In our study, blood BHB concentration at 68 days of age was not influenced by particle size of straw while straw particle size affected starter feed intake. This was in contrast to previous studies [47–49] that reported blood BHB level positively correlated with solid feed intake in calves. There was no effect of physical form of corn in starter diets on both blood BHB level and starter feed intake, regardless of forage particle size. Similar to our study, Bagheri et al. [8] reported that particle size of wheat straw offered as a free-choice provision to calves did not affect blood BHB concentration during the pre-weaning or post-weaning periods. In contrast to our result, Nemati et al. [14] found that blood BHB concentrations at 70 days of age were affected by particle size of forage in the diets offered as a TMR and were greater in calves fed medium compared to fine particle size of forage, regardless of the level of forage. These different results regarding BHB level might be due to the fact that calves were weaned earlier and consequently greater solid feed intake in the study conducted by Nemati et al. [14] compared with our study. Similar to our study, Gholizadeh et al. [26] found that physical form of corn in starter diet (ground vs whole) did not affect blood BHB concentration during the pre-weaning or post-weaning periods when the calves were fed the TMR containing 10% of chopped wheat straw. In addition, Kamyab-Fard et al. [25] also reported that serum BHB concentration was similar for the calves fed the diets with or without whole corn when comparing forage-free starter diets containing 60% ground corn versus 40.2% ground corn and 19.8% whole corn.

Blood BHB is a measure of rumen epithelial metabolic activity and indicates conversion of ruminal butyrate to β-hydroxy butyrate. Butyrate is absorbed by the ruminal epithelium and oxidized into BHB [20,48]. Deelen et al. [48] reported that blood BHB results were positively associated with ruminal butyrate in dairy calves around weaning. According to the results of our study, there was a consistent relationship between blood BHB and ruminal butyrate concentrations for all treatments except for PWCSS. Although ruminal butyrate concentration at 68 days of age was higher in PWCSS treatment than in the other treatments (PSS, PLS and PWCLS), blood BHB concentration at 68 days of age did not differ among the treatments, which might suggest that increased ruminal butyrate concentration for PWCSS treatment had limited effect on rumen epithelium maturation when considering the results of blood BHB level as an indicator of rumen epithelium development. Similar results for feed efficiency between PWCSS treatment and other treatments might confirm this suggestion since rumen papillae development is important for nutrient and VFA absorption [42,50].

In the current study, a higher fecal score indicated formation of softer feces. Mean fecal scores were higher in the calves fed straw with long particle size than those fed straw with short particle size. Calves fed the starter diets with whole corn (both PWCSS and PWCLS) had a higher mean fecal score. The highest mean fecal score was observed in PWCLS treatment. In the present study, the number of calves treated for diarrhea was one for PSS, PWCSS and PLS treatments and two for PWCLS treatment. The increase in mean fecal score for PWCLS treatment had no clinical importance when considering the number of calves treated for diarrhea. In contrast to our results, Mirzaei et al. [19] observed that fecal score was not influenced by particle size of alfalfa hay in dairy calves during the pre-weaning period when alfalfa hay was mixed with finely ground concentrates and offered as a TMR. This conflicting result between ours and that study [19] might be due to the differences in the type and particle sizes of used forage and/or the differences in the level of forage inclusion and the form of concentrates in starter diets. In our study, mean fecal score was affected by physical form of corn in starter diets. Contrary to the findings of our study, Gholizadeh et al. [26] found that fecal score was not affected by corn grain physical form (ground or whole) in starter diets of Holstein calves fed TMR containing 10% of chopped wheat straw during the pre-weaning period. Kamyab-Fard et al. [25] also reported that fecal score was not associated with different levels of whole corn in forage-free starter feeds. This discrepancy between the result of our study and that of others [25,26] was probably due to the differences in form and composition of starter diets such as amount of corn and particle size distribution.

5. Conclusions

In this study, the starter diet containing long straw and pelleted concentrate (PLS treatment) led to lower weaning BW and ADG compared to other diets (PSS, PWCSS and PWCLS treatments). This suggested that long straw combined with a pelleted concentrate might not be a suitable combination for starter diets offered as a TMR. Whole corn inclusion led to increased weaning BW, increased ADG and improved feed efficiency in the diets including long straw. In the diets containing short straw, inclusion of whole corn into calf starter (feeding a texturized starter) did not affect weaning BW, ADG and feed efficiency in pre-weaning calves. Starter feed intake was higher for the calves fed the diets including short straw compared to long straw. Physical form of corn in starter diets did not affect starter feed intake. Ruminal pH, ruminal acetate and blood BHB values at weaning were not influenced by particle size of straw and physical form of corn. In the diets with short straw, ruminal propionate, butyrate and total VFA concentrations were higher for the treatment with whole corn (PWCSS) than the treatment without whole corn (PSS). In the diets including long straw, ruminal propionate level was greater in the calves fed the diet without whole corn (PLS) compared to the calves fed the diet with whole corn (PWCLS) whereas ruminal butyrate and total VFA concentrations were similar. These results indicated that the effect of physical form of corn (ground or whole) on ruminal propionate, butyrate and total VFA concentrations could vary depending on particle size of straw in starter diets. Fecal score was affected by particle size of straw and physical form of corn. Calves fed the starter diets with whole corn (PWCSS and PWCLS) had a higher mean fecal score (softer feces). The highest mean fecal score was observed in PWCLS treatment. The findings of our study will be useful to contribute to the data on particle size of forage and physical forms of corn in starter diets offered dairy calves during the pre-weaning period.

Author Contributions: Conceptualization, Ç.K. and S.Ç.; Methodology, Ç.K., S.Ç. and A.O.; Software, Ç.K. and A.O.; Formal Analysis, Ç.K., S.Ç. and A.O.; Investigation, Ç.K., S.Ç. and N.K.K.; Resources, Ç.K. and S.Ç.; Data Curation, Ç.K., S.Ç. and A.O.; Writing-Original Draft Preparation, Ç.K., S.Ç. and N.K.K.; Writing-Review & Editing, Ç.K. and A.C.B.; Supervision, Ç.K. and A.C.B.; Project Administration, Ç.K. and S.Ç. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by TARFAŞ Agricultural Activities Production Industry and Trade Inc. (Bursa, Türkiye).

Institutional Review Board Statement: This study was conducted under a protocol approved by the Animal Care and Use Committee of Bursa Uludag University (decision no. 2022-03/13).

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors would like to thank workers of Tarfaş Holstein Dairy Farm for their help during the study.

 doi:10.20944/preprints202601.0725.v1

Conflicts of Interest: The authors declare no conflicts of interest.

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